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Mussels, Memory, and the Recorders of the Coast: A Reflective Note on Heavy Metals, Coastal Pollution, and Planetary Health

Chee Kong Yap

Department of Biology, Faculty of Science, University Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia

***Corresponding author:** Chee Kong Yap, Department of Biology, Faculty of Science, University Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia.

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Abstract

This reflective article explores the ecotoxicological significance of marine mussels, particularly Perna viridis, as sentinel biomonitors of heavy metal pollution in the coastal waters of Peninsular Malaysia. Grounded in both personal narrative and professional experience, I begin with a human health risk assessment of trace metals such as mercury, cadmium, lead, copper, and zinc in mussel tissues, and then expand into broader reflections on ecological degradation, sustainability, and planetary health. Drawing from over two decades of research, I revisit key sampling sites such as Kukup and Pantai Lido, where the act of collecting mussels became more than just scientific procedure—it became a profound engagement with ecological memory. These mussels, firmly anchored in place, silently accumulate pollutants over time, serving both as environmental sentinels and symbolic mirrors of human impact. I integrate findings from biomarker analysis, health risk modelling, and long-term Mussel Watch datasets, and highlight shell deformities and physiological stress responses as emerging indicators of environmental stress. Ultimately, I reflect on the mussel as a symbol of resilience and remembrance, and advocate for science-based coastal restoration, pollution control, and sustainable stewardship in the face of accelerating climate challenges.

Keywords: *Perna viridis*, Biomonitoring, Ecotoxicology, Heavy Metals, Coastal Sustainability.

Introduction

Listening to the Mussels

Recently, on 21 July 2025, I witnessed a quiet moment that brought me full circle. My undergraduate final-year student (IZ) (who is considered young Harimau Muda Malaya (Malaya Tiger- the most promising Malaysian scientist in the future), was preparing a specimen of the green-lipped mussel *Perna viridis* — or kupang — for dissection in our ecology laboratory (Figure 1). As I looked at the shell, I felt transported back to 1998, when I too first encountered this humble bivalve, not as an expert, but as a student driven by pure curiosity. There were no instructions, no protocols guiding me then; only my ingin tahu lebih (curiosity to know more), a personal urge to understand the life within the shell. The mussel looked exactly the same today as it did back then, which is unchanged in its form and stillness. But as I've come to learn through both science and psychology, appearances are only the tip of the iceberg. What we see on the surface, like the glistening shell, is only a fragment of a deeper story. Beneath lies what we often miss: traits, values, stress responses, and silent testimonies of pollution, etched into the mussel tissues in space and time [1].

Those field trips captured in Figure 2 and Figure 3 are more than just visual records. They are personal chapters in my journey of becoming. I still remember the weight of the mussels in my gloved hands as my former student (Mr. Frank) and I collected them at Kukup, and the way Mr. Yeow and I hunched over a worn-out tyre at Pantai Lido, scraping off mussels that had silently grown amidst floating barrels and discarded rubber, in 2005. Back then, it felt like routine sampling, but with time I came to understand: we were uncovering ecological testimonies written in shell and flesh. Each mussel we harvested was an archive of tides, toxins, space and time. What I once approached with methodological rigor, I now approach with reverence. These field moments, often overlooked, have shaped not only my scientific instincts but also my philosophical lens and outlook of life; to see mussels

not just as biomonitors, but as memory-keepers, mentors, and metaphors. Every buoy, every tide-washed jetty in those figures, still echoes with my questions, thoughts, and the quiet hope that learning is a circle we never quite complete.

Figure 1: The green-lipped mussel *Perna viridis* at the ecology laboratory to be thawed by Mr. IZ for metal analysis on 21 July 2025.

In the stillness of dawn, as coastal tides retreat and the mussels remain anchored to their rocks, there lies a language only science can interpret. These bivalves, often overlooked in their simplicity, have become the black box recorders of our coastal environments. They are both witnesses and casualties of a growing ecological debt; one that binds the health of our ecosystems to that of our bodies, one heavy metal at a time in that particular sampling site (space). Species like *Mytilus galloprovincialis* have long been recognized as effective biomonitors of coastal pollution due to their ability to bioaccumulate metals such as Cu, Zn, Pb, and Cd [2, 3]. This moment of reflection that bridging over two decades of mussel-watching, reminded me that ecotoxicology is not merely about measuring metals. It is about uncovering meanings. It is about understanding how the seen and unseen, the physical and the psychological, the body and the biosphere, are all intertwined. The mussel is no longer just an organism under my microscope, it is also a teacher, mentor, metaphor, a memory, and a mirror.

Figure 2: Field sampling activities and mussel habitat at Kukup, Johore, on 17 January 2005.

(A) A general view of the sampling site at Kukup, showing traditional wooden structures and houses built on stilts above the coastal waters. The blue barrels indicate the presence of aquaculture activities. These stilt houses form part of a coastal fishing village environment adjacent to mangrove-fringed waters.

(B)Close-up underwater image showing mussels colonizing the mesh netting. The mussels are encrusted with fouling organisms such as algae and barnacles, indicating their natural growth conditions under aquaculture settings.

(C) Field sampling in progress: Me and Franklin (my final year project undergraduate student) are seen collecting mussels directly from submerged structures. Both are wearing life vests for safety, and the mussels are being retrieved manually from aquaculture lines or nets tethered to floating systems.

(D) Me is shown individually retrieving mussels from a buoyant aquaculture raft structure situated in a brackish mangrove-lined channel. The activity reflects hands-on sampling work critical for subsequent laboratory analysis of mussel tissues for environmental monitoring.

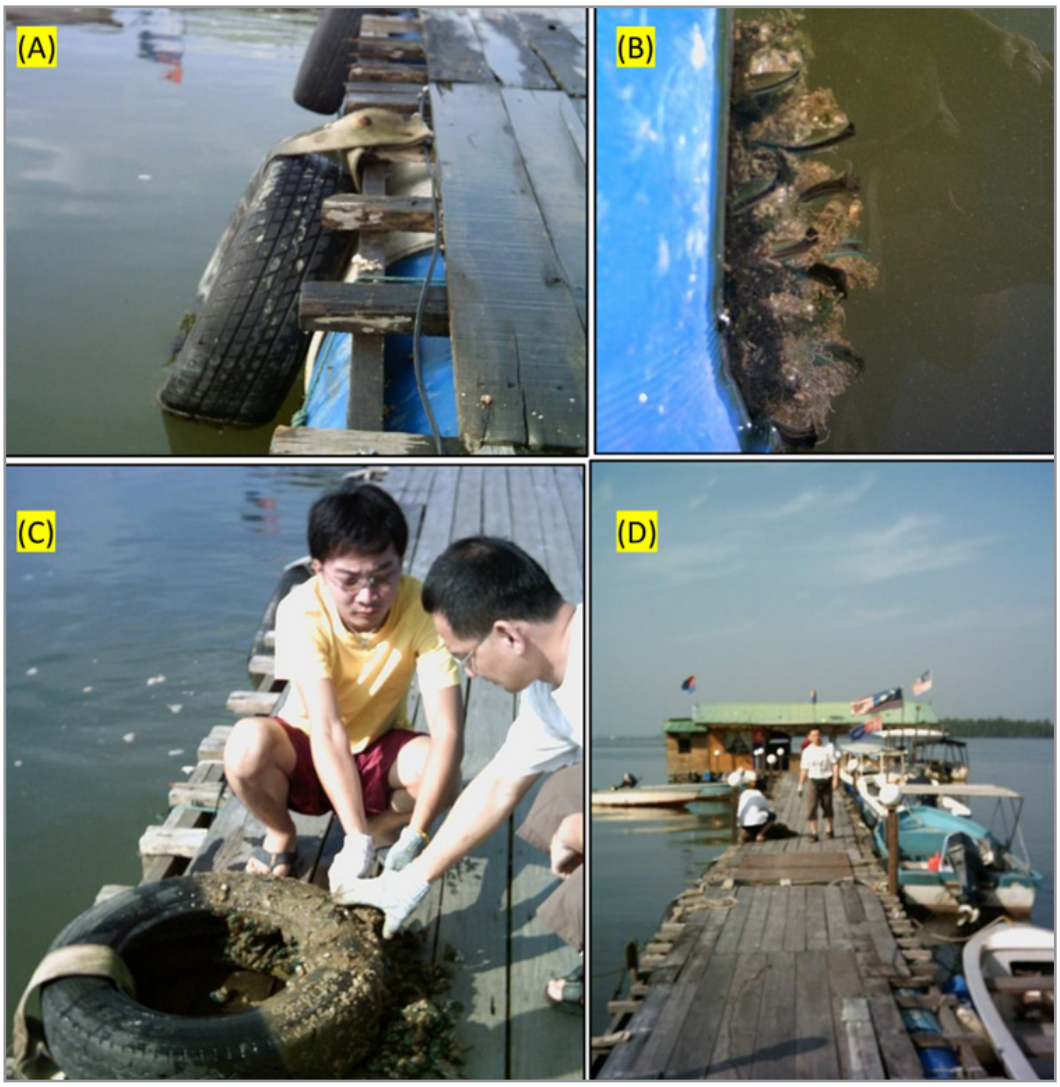

Figure 3: Field sampling activities and mussel habitat at Jetty Pantai Lido, Johore, on 18 January 2005.

(A) A close-up image of the wooden walkway structure extending over coastal waters, where used tyres and plastic drums serve as flotation devices and artificial substrates for mussel colonization. These tyres function as passive collectors for mussels, offering a shaded, rough surface suitable for attachment.

(B) A submerged view of mussels firmly attached to the blue plastic barrel at the edge of the jetty. The mussels have grown in clusters, indicating their natural settlement in this anthropogenic structure subjected to tidal influence and organic-rich waters.

(C) Active sampling in progress: Me and Yeow were hand-picking mussels from a tyre that had been removed from the jetty's edge. Both individuals are wearing gloves to ensure safety and hygiene while collecting specimens for further laboratory analysis. This hands-on sampling reflects direct mentorship and collaborative fieldwork.

(D) A wider view of the wooden jetty extending into the water body at Pantai Lido. The image captures the ongoing sampling trip where boats and floating structures serve as platforms for environmental monitoring. Me was seen mentoring students, emphasizing experiential learning in coastal field ecology.

The objective of this reflective article is to examine and communicate the ecotoxicological importance of marine mussels, particularly *P. viridis*, as biomonitors of heavy metal contamination in Peninsular Malaysia's coastal waters, while intertwining this scientific exploration with personal field experiences, professional and layman reflections. By revisiting two decades of mussel-based environmental monitoring, including health risk assessments and bioaccumulation studies at key sites like Kukup and Pantai Lido, I aim to highlight how mussels serve not only as indicators of ecological health but also as symbolic carriers of memory, resilience, and environmental truth. Through this integration of data, fieldwork, and introspection, this reflection note seeks to inspire a deeper awareness among researchers, students, and policymakers of the interconnectedness between human health, marine ecosystems, and long-term sustainability or what is termed as planetary health nowadays.

Human Health: The Body as an Estuary

In ecotoxicology, we begin with the body. Copper in the liver, cadmium in the kidney, lead in the blood in which these potentially toxic metals find their ways from sea to human stomach, from pollution to pathology. Every risk assessment I perform, every Target Hazard Quotient I calculate, is not just a number; it is a signal. It speaks of mothers who feed their children seafood, unaware of the trace threats within. It speaks of fishermen whose livelihoods now harvest not abundance, but anxiety.

Human exposure through the consumption of mussels has been evaluated in multiple regions, revealing that while acute health risks may be low, the long-term cumulative exposure remains a significant concern [4-6]. The use of mussels (*P. viridis* and other bivalves) as biomonitors has become increasingly relevant in coastal regions such as Kukup, Johore, where Figure 2 provides a visual testimony to this practice.

Figure 2 captures the real-world context in which these ecotoxicological assessments are grounded. In Figure 2A, the aquaculture setup at Kukup displays the interconnection between human settlement and the aquatic environment, where floating barrels and wooden stilts act as informal mussel farms and simultaneously, as pollutant sinks. Figure 2B dives beneath the surface to show mussels encrusted with algae and fouling organisms, embedded in a net, a micro-ecosystem of bioaccumulation. These mussels, thriving in contaminated waters, silently concentrate metals like copper, cadmium, lead, nickel, and zinc into their soft and hard tissues.

In Figure 2C, field sampling is not merely a technical act; it becomes a ritual of bearing witness. Frank and I, shown collecting mussels by hand, are not just researchers; we are intermediaries between ecosystem health and human safety. The gloves we wore were not just for hygiene, but a symbolic barrier between the polluted marine life and our own vulnerability. Figure 2D depicts me retrieving mussels directly from floating buoys as part of a systematic effort to translate environmental data into human risk awareness.

These sampling activities are more than procedural steps; they are embodied acts of public health surveillance. Every mussel dissected and every shell scraped clean is a chapter in a larger narrative of coastal degradation and food insecurity. We often think of coastal waters as distant and separate. But human bodies are their estuaries, connected by seafood, sediment, and survival.

Monitoring these levels is essential not only for ecological safety but for public health, especially in areas with high seafood dependence such as southern Johore. Studies have consistently confirmed the biomagnification potential of heavy metals through the food chain, necessitating continued vigilance [7, 8, 9]. The body, especially of those most reliant on marine proteins becomes the final reservoir for these invisible intrusions. The estuary is not just out there; it is in us.

Coastal Ecosystems: Mussels as Memory-Keepers

Mussels do not migrate. They do not run from mercury or zinc. Instead, they stay as steadfast sentinels, filtering gallons of water, absorbing heavy metals, and archiving pollution. In them, I see the metaphor of responsibility. In every *P. viridis* or *M. galloprovincialis* shell lies a history book of our coastal behaviours, industrial footprints, and lax environmental policies [10, 11].

Figure 3 illustrates this metaphor in action at Jetty Pantai Lido (southern Johore), where field observations highlight how mussels embed themselves within man-made substrates such as tyres, plastic barrels, and wooden jetty structures that turning human debris into ecological archives. In Figure 3A, we see a tyre attached to a weathered jetty, serving not merely as flotation support but as an artificial reef. The calm water beneath hides colonies of filter feeders. These rubber structures, once designed for mobility, now anchor biological stillness which is a paradox of discarded industry becoming a vessel for environmental truth.

Figure 3B takes us closer, showing mussels growing in thick, resilient clusters along the side of a blue floating barrel. These mussels have quietly documented years of water quality fluctuations, absorbing and retaining metals from industrial discharge and urban runoff. Their shells and soft tissues become proxies for long-term contaminant trends, offering invaluable temporal records often overlooked by conventional water sampling techniques.

In Figure 3C, the physical act of extraction becomes an act of ecological archaeology. Together with my student Mr. Yeow, we hand-picked mussels from a removed tyre, uncovering not only biological specimens but embedded stories of pollution tolerance, growth anomalies, and shell microstructure disruptions. Each shell, roughened and layered, serves as a palimpsest etched with the imprint of environmental stressors.

Figure 3D expands the scope of our fieldwork: mentoring students during real-time sampling not only builds technical capacity but also transfers ecological ethics. The image captures more than just data collection. It preserves a pedagogical process wherein students come to understand mussels not merely as specimens, but as ecological memory-keepers.

Heavy metals from industrial discharges, agricultural runoff, and maritime activities have been recorded globally, and mussels offer spatial and temporal insight into these patterns [12]. Mussel Watch programs provide essential long-term datasets to support policy reform and adaptive management strategies [13, 14]. These datasets often initiated through humble sampling like

that seen in Figures 2 and 3 that become pillars for environmental governance.

In the physiological responses of mussels, oxidative stress, enzymatic shifts, or tissue lesions, lie early warning signals of ecosystem collapse [15, 16]. Additionally, shell deformities have been documented in *P. viridis* as responses to multiple environmental stresses, adding new layers of morphological biomonitoring tools [17]. Such deformities can often be traced back to sites like Pantai Lido, where mussels have long been exposed to complex mixtures of pollutants.

Ultimately, mussels remain at the confluence of human negligence and natural resilience. They are not just indicators, they are witnesses. And as long as they continue to grow on our forgotten tyres and floating barrels, they will continue to remind us that the story of the coast is not written in sand, but in shell.

Climate Change: Shifting Tides and Intensified Risks

Climate change is not merely atmospheric. It is biological. The warming sea alters metal speciation. Ocean acidification affects bioaccumulation rates. Salinity changes disrupt feeding behaviour and enzymatic stability. The ecotoxicological equations I once trusted become less predictable. Mussels, previously stable indicators, now reflect this uncertainty, embodying the compounded stress of pollution and climate change [18].

As sea levels rise and coastal temperatures climb, baseline conditions shift. The biomarker systems once calibrated under stable climatic regimes now must be reconsidered in fluctuating ones. Mussel farming, often praised for sustainability, must now contend with both contamination risks and climate variability [7]. Still, in every mussel tissue sample, I find resilience which is a resistance to surrender, a biological call to action.

5. Sustainability and Planetary Health: Relearning Interdependence

Sustainability is no longer a slogan; it is a survival strategy. Planetary health demands that we acknowledge the interconnectedness of all systems, covering oceanic, ecological, and human. My research on heavy metals in mussels is no longer just about environmental monitoring. It is about advocacy. It is about translating metal concentrations into regulatory dialogues, public engagement, and curriculum reforms.

Marine mussels serve as global sentinels for planetary health. They reveal not only the environmental burden we place on coastal ecosystems but also reflect our readiness to act. Programs like Mussel Watch offer hope by standardizing global comparisons, thereby influencing both regional and international policy dialogues [3, 12]. Their use as ecological indicators also helps in framing ecosystem service values in the face of global changes [18]. Genetic variation studies in *P. viridis* populations further reinforce the need to preserve adaptive biodiversity in polluted habitats, while baseline concentration studies help distinguish between anthropogenic and natural metal levels [19, 20].

Conclusion

The Coast Is a Mirror, Not a Margin

As an ecotoxicologist in this region, I have learned that coastal ecosystems are not peripheral. They are central. They are mirrors of our choices, archives of our negligence, and still, somehow, reservoirs of hope. Each mussel I dissect is not just a sample; it is a story. A reminder that sustainability begins with humility, with listening to ecosystems before they collapse into silence.

In our quest to secure planetary health, perhaps it is time we emulate the mussel: resilient, grounded, and ever-watchful. For the coast does not forget, and neither should we.

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